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Application of a Novel 3D-Printed Nasal Plug as a Conservative Treatment for Empty Nose Syndrome

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Objective: Empty nose syndrome (ENS) is commonly treated by surgery, albeit with limited success. Herein, we introduce our experience of applying a newly developed "3D-printed nasal plug" as an alternative conservative treatment modality.

Methods: This retrospective study included 20 patients (14 males, 6 females; mean age 46.5 ± 13.5 years) with ENS who underwent the application of the 3D-printed nasal plug at Asan Medical Center between June 2022 and May 2023. Symptom improvement was assessed by Empty Nose Syndrome 6-Item Questionnaire (ENS6Q) before and after applying the nasal plug. Clinical results, such as duration and frequency of plug use, discomfort, and level of satisfaction, were investigated.

Results: The mean follow-up duration was 40.3 ± 24.2 weeks. The average duration of nasal plug usage was 10.8 h per day and 5.3 days a week. The ENS6Q scores improved from 19.6 ± 4.6 to 6.8 ± 5.1 (mean reduction 12.8 ± 5.9) after 30 minutes of wearing. Symptom "nose feelings too open" was improved most by a score of 3.0 ± 1.5 ($p < 0.001$). Thirteen patients (65.0%) reported that the effectiveness of the plug, initially confirmed at the first wearing, was well maintained during the entire follow-up. Four patients (20.0%) wore the nasal plug uninterruptedly throughout the week, whereas nine patients (45.0%) wore it intermittently as needed. Frequently reported complaints with plug usage were 'displacement of the plug' and 'cosmetic concerns' about the visible hook portion.

Conclusion: A 3D-designed nasal plug can be a useful conservative treatment option for ENS patients.

Key Words: empty nose syndrome, nasal cavity, nasal prosthesis, three-dimensional printing.

Level of Evidence: 4

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INTRODUCTION

Empty nose syndrome (ENS) is a rare and controversial complication that emerges postoperatively due to the excessive loss of turbinate volume during turbinate surgery.[1,2] Its symptoms include the lack of airflow sensation despite objective evidence of a patent nasal airway.[2,3] ENS is frequently accompanied by dyspnea, nasal dryness, crusting, sensation of suffocation, or nasal burning.[4] Furthermore, the deterioration of the quality of life resulting from typical symptoms contributes to psychiatric comorbidities, including depression, anxiety, panic attacks, and occupational dysfunction.[5]

Despite the increasing attention to the clinical impact of ENS, its treatment remains challenging. To date, the mainstay treatment for ENS is inferior meatus augmentation surgery. However, there is a limitation that a considerable number of patients do not respond favorably to surgical intervention, and complications such as over-correction, chronic rhinosinusitis, under-correction, resorption, and extrusion may occur.[6–10] Moreover, due to the lack of effective and more conservative treatment alternatives, an effective conservative treatment option would be of great help to both patients and doctors.

Most of the previously reported conservative treatments focused on humidification and anti-inflammatory mechanisms. Clinicians often applied treatment modalities such as nasal lavage, saline sprays, moisturizing ointments, and topical steroids. However, their effectiveness has yet to be confirmed, and there is currently no standardized way of applying those options. Conservative measure such as self-made cotton packing that modifies nasal airflow has been tried by some patients, but it tends to be unsanitary with extended use and yields inconsistent therapeutic outcome. Hinted by self-made packing adopted by the patients, we developed a wearable plug that offers airway resistance suited to the patients' altered nasal cavity structure. Using 3D printing technology, we manufactured customized nasal plugs based on individual anatomical characteristics of the patient's computed tomography (CT) scans. Herein, we present our experience with this novel approach, highlighting its clinical efficacy and the potential as a personalized conservative solution in ENS treatment.

MATERIALS AND METHODS

Patients

This study assessed 20 patients diagnosed with ENS between June 2022 and May 2023 at Asan Medical Center.

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Twenty patients were included in the study, comprising 14 males and 6 females, with a mean age of 46.5 ± 13.5 years (range, 28–70 years). The average follow-up period was 40.3 ± 24.2 weeks (range, 8.4–109.9 weeks). The criteria for ENS diagnosis were the presence of typical ENS symptoms, a history of turbinate surgery, ≥11 points confirmed in the validated empty nose syndrome 6-item questionnaire (ENS6Q), and a reduction in the turbinate volume verified by either endoscopic examination or CT image.

A cotton test was performed on patients who met the aforementioned criteria to determine the improvement of the symptoms of ENS after cotton placement. Without local anesthesia, a small dry cotton was placed in the inferior meatus to fill the turbinate defect. The patients were requested to report any alleviation in their symptoms afterward. In case of symptom improvement, the patient was instructed to wear a customized nasal plug fabricated based on the anatomical characteristics of the patient's ostiomeatal-unit CT (OMU-CT).

The ENS6Q is a validated, disease-specific questionnaire which can aid in making the diagnosis of ENS and quantifying the outcome measure for the improvement of symptoms in ENS patients.[2,11] ENS6Q scores before and 30 minutes after wearing the plug in the clinic were analyzed. To verify the plug's sustained efficacy and patient satisfaction, an outpatient follow-up observation was conducted 1 month after the initial usage to assess the overall usage pattern of the nasal plug, including the items such as the frequency and time of use, inconvenience, side effects, and reasons for discontinuation. Patients were educated to clean their nasal plugs daily with normal saline and regularly disinfect them with an alcohol swab.

We excluded patients whose follow-up period was <1 month or those whose compliance could not be determined due to follow-up loss. If a patient using nasal plug received any other treatment intervention related to ENS, such as surgery, their medical record was investigated only up to the point before that intervention occurred. The present study was approved by the Institutional Review Boards of Asan Medical Center, Seoul, Korea. Written informed consent concerning the study was obtained from all patients prior to the trial.

Manufacturing 3D-Printed Nasal Plug

An OMU-CT was taken to evaluate the shape and extent of the inferior turbinate defect and its surrounding nasal structures. A 3D reconstruction of the CT image was made to aid in the modeling of a nasal plug suitable for filling the presumed defect at the head of the inferior turbinate. The customized nasal plug was manufactured using a mold designed with stereolithography apparatus (SLA) 3D printer, ProJet 7000 (3D-Systems Inc, Rockhill, SC, USA), which involves vat photopolymerization exposing the resin to ultraviolet laser (Fig. 1A–C).[12] This high-resolution process is frequently employed for the production of end-use parts with fine features and smooth surfaces in various fields, including medical implants.

The structure of 3D-designed nasal plug consisted of two main parts: the "head part" that fills the defect of the inferior turbinate and the "external loop" designed to fit in the alar groove (Fig. 1D). The head part was shaped like a kidney bean with a contour that fills the missing part of the inferior turbinate to allow a stable fit within the nasal cavity (Fig. 2A,B). The external loop was a slender C-shaped hook connected to the head part designed to externally conform to the alar groove for the fixation (Fig. 2C,D).

Both the head part and the external loop were made of a shape memory polymer (SMP), which has the physical characteristics of a rubber-like soft state above its glass transition temperature (35°C). The final shape of the nasal plug was formed by vacuum-casting method using a blend of polyurethane elastomer and hardener in the 3D-printed mold. When placed in the patient's nasal cavity, the head portion snugly filled the defect, touching the turbinate and lateral wall mucosa. The external loop had a greater elasticity than the head portion, which ensures better conformance to the curvature of the ala and anchors to the nasal ala groove. The material was colored to closely match the patient's skin color. The patients were instructed on how to remove the nasal plug, to clean, and to comfortably relocate it as needed in their daily life.

Statistical Analysis

Demographic characteristics and treatment history were summarized by counts and absolute frequencies. Clinical outcomes related to the use of nasal plug (mean usage time a day, mean frequency of use per week, satisfaction, side effects, and complaints) were recorded and analyzed.

ENS6Q scores before and after 30-min application of nasal plug were investigated and paired samples t-test was used to compare the change in mean differences. Mann–Whitney *U*-test was conducted to assess the average ENS6Q scores between each satisfaction group, and Fisher's exact test to identify the potential risk factors influencing satisfaction and maintenance of the nasal plug usage. $p < 0.05$ was considered statistically significant, and 95% confidential intervals were reported. All statistical analyses were performed using Statistical Package for Social Sciences version 23 (SPSS Inc., Chicago, IL, USA).

RESULTS

The mean follow-up duration of 20 patients was 40.3 ± 24.2 weeks. All patients had a history of undergoing at least one turbinate surgery in other hospitals and were referred to our medical center for further evaluation and management. Among them, 14 patients (70%) underwent turbinectomy, four patients (20%) underwent radiofrequency ablation volume reduction, and two patients (10%) underwent submucosal turbinoplasty.

The average ENS6Q total score was 19.6 ± 4.6 points before nasal plug application. The average total score after wearing the nasal plug was 6.8 ± 5.1, resulting in a significant reduction of 12.8 ± 5.9 points (95% confidence interval [CI]: 10.027–15.573, p < 0.001). Nineteen patients (95%) reported sustained symptom relief for 1 month since application in the clinic. Fifteen patients (75%) had more than a 7-point reduction in ENS-6Q score, which is considered as the minimal clinically important difference (MCID) in the ENS6Q test.[13]

As regards the symptom score, the item "nose feelings too open" was the highest with 4.4 ± 0.7 points, followed by "dryness" with 4.0 ± 1.3 points. Meanwhile, "nose feels too open" showed the largest score change (3.0 ± 1.5 points; 95% CI: 2.230–3.670, $p < 0.001$), followed by "dryness" (2.8 ± 1.6 points; 95% CI: 2.047–3.553, $p < 0.001$), "suffocation" (2.2 ± 1.7 points; 95% CI: 1.372–2.928, $p < 0.001$), "lack of sensation" (2.0 ± 1.9 points; 95% CI: 1.102–2.898, $p < 0.001$), "burning" (1.5 ± 1.5 points; 95% CI: 0.654–2.246, $p = 0.003$), and "crusting" (1.5 ± 1.0 points; 95% CI: 0.699–2.201, $p = 0.002$). Therefore, the symptoms that patients

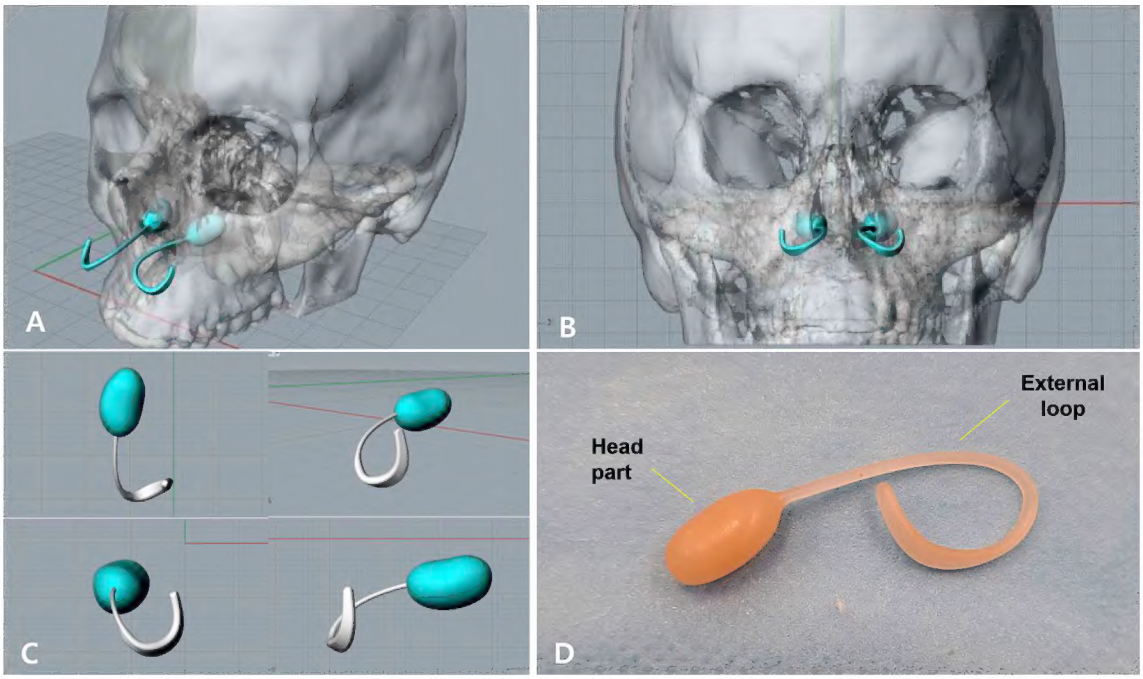

Fig. 1. A 3D modeling of facial bone and nasal plug based on individual CT scan (A–C). Picture of two main parts of the nasal plug: head part and external loop (D).

complained about most before treatment showed the greatest improvement after wearing the nasal plug (Table I).

We evaluated the ENS6Q score change observed at the cotton test. The average ENS6Q score before and after the cotton placement was 16.5 points and 7.6 points, respectively, resulting in a reduction of 8.9 points. The ENS6Q score changes between the cotton test and the nasal plug were significantly correlated ($R = 0.589$, $p = 0.027$) (Fig. 3).

Patients' compliance and satisfaction were evaluated 1 month after initiation of the nasal plug use. Of the 20 patients, 16 patients (80%) used a nasal plug for at least 1 month, and the average usage period for all patients was 120.6 ± 87.4 days. The average duration of nasal plug use was 10.8 h per day and 5.3 days per week. Until the last follow-up, 13 patients (65%) used the nasal plug (Table II). Among them, four patients (20%) continued to uninterruptedly use the nasal plug 7 days a week and 24 h a day, even during outdoor activities, demonstrating excellent compliance. The remaining nine patients (45%) maintained the use of the nasal plug intermittently as-needed basis for symptom management. For example, they applied their nasal plug on days when symptoms were severe, especially at home or during sleep.

In terms of satisfaction, patients were asked to rate their subjective satisfaction with wearing the nasal plug and categorize them into four levels (Excellent, Good, Moderate, and Poor). The responses were as follows: Excellent, four patients (20%); Good, eight patients (40%); Moderate, five patients (25%); and Poor, three patients (15%), respectively (Table II). All patients who rated their satisfaction above the moderate level reported their symptomatic improvement initially experienced upon wearing was continuously sustained during the whole period of their usage of the nasal plug.

Seven (35%) patients discontinued nasal plug use. Four patients (20%) stopped using them despite good effectiveness due to "surgical treatment during the study period ($n = 2$, 10%)," "mobility of the plug not staying in place properly ($n = 1$, 5%)," "visibility of the external loop ($n = 1$, 5%)." Three patients (15%) were unsatisfied with the effectiveness and quit using the nasal plug owing to "foreign body sensation ($n = 1$, 5%)," "excessive nasal discharge ($n = 1$, 5%)," and "diminishing effectiveness over time ($n = 1$, 5%)" (Table III). Discomfort or adverse reaction caused by plug use includes displacement due to poor fixation ($n = 13$, 65%), cosmetic concerns due to external loop ($n = 12$, 60%), foreign body sensation ($n = 4$, 20%), runny nose ($n = 3$, 15%), pain ($n = 1$, 5%), and itching ($n = 1$, 5%). (Table III).

DISCUSSION

The nasal concha, especially the inferior turbinate, is essential for the maintenance of nasal airflow resistance. Loss of turbinate volume leads to deranged nasal airflow which is thought as one of the main mechanisms contributing to ENS.[14] Thus, surgical treatments have mainly aimed to restore the resistance of the nasal cavity by augmentation.[15,16] We developed a novel conservative treatment option for ENS via a 3D-printed wearable nasal plug. In this study, we demonstrated its acceptable efficacy in relieving the symptoms of ENS patients,

suggesting its usefulness as a conservative treatment option for ENS.

Due to the lack of a gold standard to confirm the diagnosis of ENS, diagnostic criteria mainly involve symptomatology, image findings, and ENS-specific tests.[17] We used two validated tools, ENS6Q and office-based cotton test, to confirm ENS diagnosis and evaluate the clinical improvement with the nasal plug. ENS6Q comprises six questions quantifying the severity of the ENS symptoms, in which a patient who scores more than 11 points is likely to be diagnosed with ENS.[2] In the present study, patients diagnosed with ENS based on four criteria (symptoms, history, imaging, and ENS-specific test) were included. The mean initial ENS6Q score in our study group was 19.6 ± 4.6, which is consistent with average scores in the literature.[2,13,18]

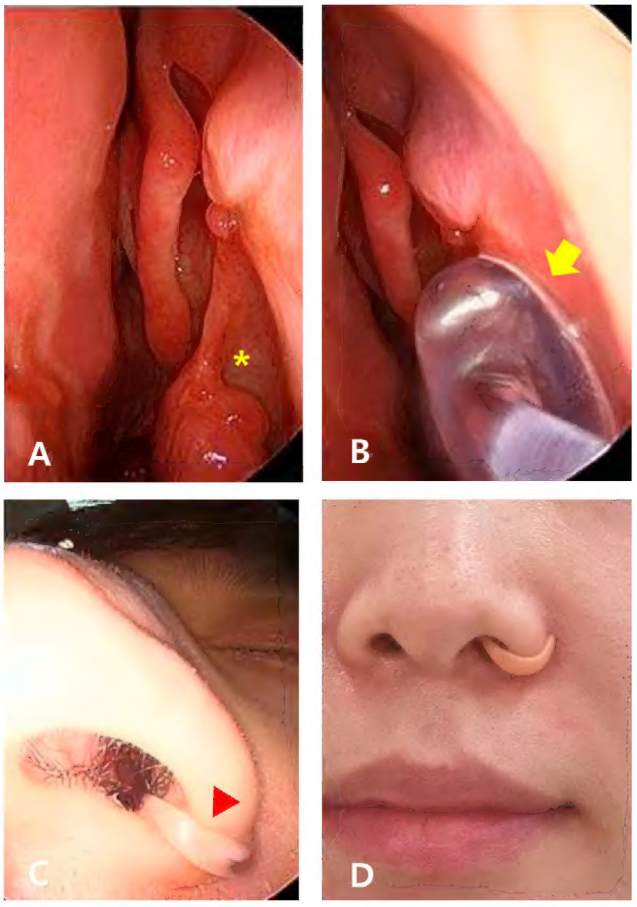

Fig. 2. Application of the nasal plug. Endoscopic view of left nasal cavity before the nasal plug use. There is a defect of the inferior turbinate due to previous turbinate surgery (asterisk) (A). Endoscopic view after the nasal plug use, where head prosthesis fills the defect (arrow) (B). External loop (arrowhead) spans along the alar groove fixing the nasal plug (C,D).

The cotton test is a simple, reliable, office-based method that helps the accurate diagnosis and prognostication of ENS. It is a valid objective measure that can assist in identifying potential surgical candidates who would benefit from turbinate augmentation surgery.[4,13] Given that the nasal plug has a similar mechanism of treatment with inferior meatus augmentation surgery, which reestablishes nasal airway resistance by replacing the missing volume, we speculated that the cotton test may provide us with potential beneficiary of the nasal plug. Our results showed that changes in ENS6Q score in the nasal plug treatment group were positively correlated with that of the cotton test ($R = 0.589$), implying that the cotton test could be helpful in identifying the patients who may benefit from nasal plug treatment.

Some patients personally and continuously used self-made cotton packing to alleviate their ENS symptoms. However, daily use of cotton packing carried the risks of migration of the cotton over time, poor hygiene of the nasal cavity, and occasional swallowing. Our nasal plug is made from a safety-proven shape memory polymer, featuring a texture like an easy-to-clean plastic and an external loop that fits the alar groove that prevents the risk of swallowing and migration. Moreover, it can become slightly soft at a temperature above 35°C, causing less irritation to the nasal mucosa. In reality, among the patients, only four (20%) complained of a feeling of a foreign body inside the nose associated with plug use, and only 1 (5%) discontinued the nasal plug use due to this discomfort. Thus, SMP, the material used for making the plug, has beneficial physical characteristics in terms of better compliance.

Our nasal plug demonstrated its convenience and safety as a new promising conservative therapy by showing acceptable treatment outcomes. Using the nasal plug,

TABLE I.
Comparison of the ENS6Q Scores (Total Scores and Item-Specific Scores) Before and After Nasal Plug Placement ($N = 20$).

Symptoms	Before nasal plug use	After nasal plug use	*p*-value
Total ENS6Q score	19.6 ± 4.6	6.8 ± 5.1	<0.001*
Dryness	4.0 ± 1.3	1.2 ± 1.2	<0.001*
Lack of sensation	3.6 ± 1.4	1.6 ± 1.3	<0.001*
Suffocation	3.2 ± 1.4	1.1 ± 1.1	<0.001*
Feels too open	4.4 ± 0.7	1.5 ± 1.3	<0.001*
Crusting	2.3 ± 1.8	0.9 ± 1.1	0.002*
Burning	2.2 ± 1.9	0.7 ± 0.9	0.003*

All values are mean ± SD.
*Statistically significant.

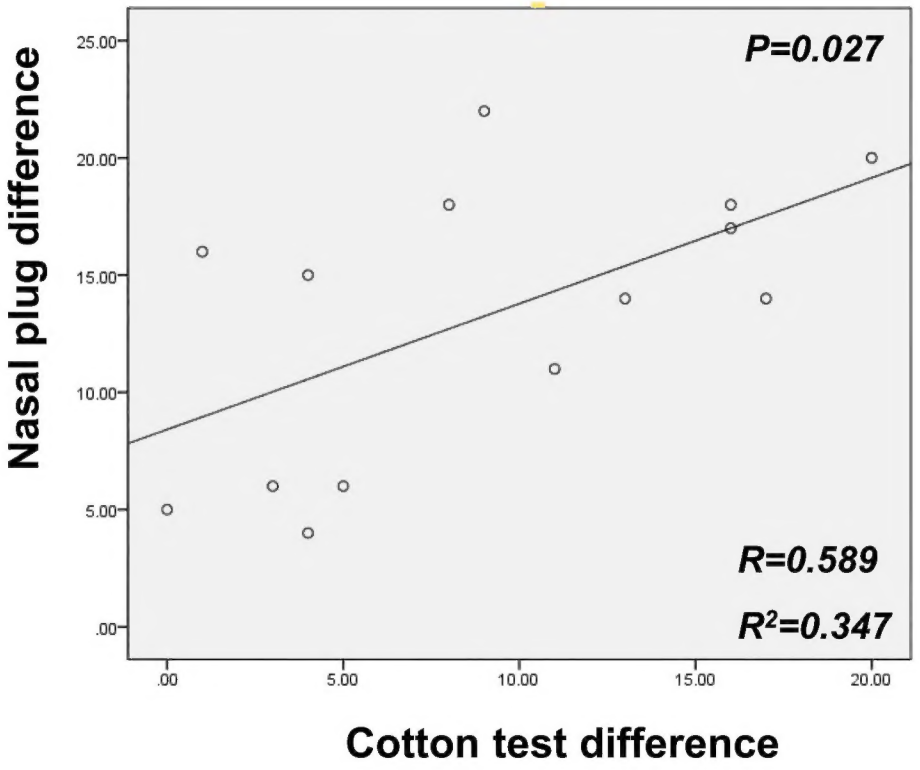

Fig. 3. A scatterplot that shows relationships between ENS6Q difference in nasal plug application and cotton test. A moderate positive correlation is confirmed ($R = 0.589$, $p = 0.027$).

TABLE II.
Compliance and Satisfaction.

Variables	Number (%) ($N = 20$)
Duration of usage	
Usage hours per day, mean + SD, hours	10.8 ± 7.2
Usage days per week, mean + SD, days	5.3 ± 2.0
Pattern of usage at the last follow-up	
Maintained usage	13 (65)
Uninterrupted usage for a whole day	4 (20)
Intermittent usage as-needed basis	9 (45)
Discontinuation	7 (35)
Subjective satisfaction at the last follow-up	
Excellent	4 (20)
Good	8 (40)
Moderate	5 (25)
Poor	3 (15)

TABLE III.
Complaints and Reasons for Discontinuation.

Variables	Number (%) ($N = 20$)
Complaints	
Displacement due to poor fixation at the alar groove	13 (65)
Cosmetic concerns	12 (60)
Foreign body sensation	4 (20)
Runny nose	3 (15)
Pain	1 (5)
Itching sense	1 (5)
Reasons of discontinuation	
Planned surgical intervention	2 (10)
Displacement due to poor fixation	1 (5)
Cosmetic concerns of external loop	1 (5)
Foreign body sensation	1 (5)
Excessive nasal discharge	1 (5)
Diminishing effectiveness	1 (5)

Numbers are not mutually exclusive.

patients experienced a considerable symptomatic improvement, with an immediate mean ENS6Q score reduction of 12.8 ± 5.9, and the clinical effect of the nasal plug was well maintained at the 1-month follow-up. Previous research studying surgical outcomes of inferior meatus augmentation confirmed the ENS6Q difference varying from 5.3 to 15.0 at the last follow-up,[19–25] suggesting that the nasal plug may have comparable therapeutic effects with surgical intervention. Therefore, we cautiously suggest that our nasal plug can be utilized even as a primary treatment option obviating the need for surgical intervention, especially for patients who are reluctant to surgical intervention and prefer a conservative approach.

Patients showed higher compliance with the nasal plug than expected and were sufficiently satisfied with its actual use in daily life. In the satisfaction survey conducted after more than 1 month of actual use, 12 patients (60%) responded as excellent or good, and 13 patients (65%) continued to use the nasal plug up to the last survey follow-up observation, indicating sufficient satisfaction with real-life use.

Patients who desired surgical treatment because their initial clinic visit showed satisfaction with the nasal plug, suggesting the possibility of the nasal plug as an interim prosthesis even for patients who preferred surgery. In subsequent studies, we may consider applying ready-made nasal plugs with several different sizes to avoid the time-consuming CT-based customization procedure. In addition, nasal plug holds potential to forecast post-surgical treatment outcomes and be a viable adjunctive treatment option for cases of under-correction that have not been fully corrected post-surgery.

However, the limitation of the nasal plug lies in its design, where the conspicuous external loop—an inevitable design component to stabilize the positioning of the plug—results in a cosmetic problem. We customized the color of the external loop to match the patient's skin tone to lessen the visibility of external loop. Nevertheless, the external appearance remains to deter patients from using the nasal plug. Another limitation is that even with a customized 3D design based on CT scans, the head part could not achieve a complete compensation of the tissue defect nor a perfect fitting of the external loop to the alar groove. Although challenging, future design considerations should address providing stable fixation and concealing the support within the nose to reduce visibility.

The present study has certain limitations. First, the overall number of patients included in the study was relatively small. Second, there was no control group, and thus other conservative treatment methods could not be directly compared with our approach. Third, the observation period was relatively short. Fourth, we were unable to evaluate the impact of the nasal plug on nasal hygiene. Lastly, we solely relied on the change in the ENS6Q score for the measurement of symptom improvement, lacking other parameters related to quality of life and mental health. This suggests the necessity of further study with a longer follow-up period and other evaluation tools, including Sino-Nasal Outcomes Test 25 (SNOT-25).

CONCLUSION

The 3D-printed nasal plug has promising potential as a useful conservative treatment option for patients with ENS.

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